

Document 3**A DESCRIPTION OF THE WEST COAST AERIAL SARDINE SURVEY**

Prepared for
*WORKSHOP ON ENHANCING STOCK ASSESSMENTS OF PACIFIC SARDINE IN
THE CALIFORNIA CURRENT THROUGH COOPERATIVE SURVEYS*

June 1-3, 2010
La Jolla, California

By

Tom Jagielo
PO Box 93
Copalis Beach, WA 98535

Doyle Hanan
Rancho Sante Fe, CA

Consultants for the West Coast Sardine Survey

I. Introduction and Background

Advisory bodies of the Pacific Fishery Management Council (Council), including the Coastal Pelagic Species Advisory Subpanel (CPSAS), the Coastal Pelagic Species Management Team (CPSMT), and the Scientific and Statistical Committee (SSC), have recommended that additional fishery-independent indices of abundance be developed for the assessment of Pacific sardine. In 2008, the Northwest Sardine Survey (NWSS), an industry group based in the U.S. Pacific Northwest, developed and successfully tested an aerial survey methodology intended to provide additional data for sardine abundance indices (Wespestad et al. 2009). The objective of that pilot study was to determine if estimates of absolute sardine abundance could be obtained by this methodology for inclusion in the West Coast Pacific sardine stock assessment model.

A stock assessment review (STAR) panel examined the NWSS aerial sardine survey design in May 2009. Two key issues of the review addressed: 1) the ability of the survey design to estimate absolute abundance (vs. trends in abundance) and 2) the use of aerial survey abundance estimates in stock assessments for Pacific Sardine. The panel noted that the survey method provided "... an estimate of a minimum [abundance], at least." In addition, the panel noted, "... It is anticipated that if the surveys continue over multiple years, it would provide a basis for a new relative index of abundance."

The Council subsequently approved an Exempted Fishing Permit (EFP) application, submitted by an industry consortium (the West Coast Sardine Survey -- formed by NWSS and the California Wetfish Producers Association (CWPA)), to conduct a coastwide aerial sardine survey in the summer of 2009. Survey work conducted under the sardine EFP in 2009 extended from Cape Flattery, Washington, to Monterey Bay, California. Results of the 2009 aerial sardine survey were reviewed by a STAR panel in September 2009 and were approved as an estimate of absolute abundance for use in the 2009 Pacific sardine stock assessment (Hill et al. 2009).

At this writing, an EFP application to conduct Pacific sardine survey work in 2010 has been approved by the Council and presently awaits NMFS approval. The 2010 study design uses the methods employed in 2009, and extends survey coverage further southward (to the southern California Bight), and potentially further northward into Canada (contingent upon approval of the Canadian Government). As in 2009, the 2010 survey will be a coordinated effort by the two

regional industry groups (NWSS and CWPA). Additionally, the CWPA will conduct a fall 2010 pilot survey in southern California, to assess alternative survey methods including Light Detection and Ranging (LIDAR) and acoustics, for review in a sardine STAR panel planned for 2011.

The purpose of this paper is to provide a description of the West Coast Aerial Sardine Survey for purposes of discussion at the *Workshop on Enhancing Stock Assessments of Pacific Sardine in the California Current through Cooperative Surveys* (Workshop), scheduled for June 1-3, 2010 in La Jolla, California. Included here are summary descriptions of: 1) the scientific study design, 2) the analysis methods employed, and 3) basic survey logistics.

Advantages of Using Aerial Photographic Imagery to Measure Sardine Schools

After compiling and reviewing the information presented in Table 1, the May, 2009 STAR panel concluded that factors leading to underestimation of absolute biomass in general outweighed the factors leading to overestimation of biomass. This property of the survey is advantageous, in that overestimation is clearly a property to be avoided for stock assessment purposes. Thus, the aerial survey method is considered to be a minimum estimate of absolute abundance.

An advantage specific to the aerial transect approach (when compared to the use of satellite imagery) is that it makes use of experienced spotter pilots, who provide at-sea observations to assist with species identification.

Challenges and Limitations of Using Aerial Photographic Imagery to Measure Sardine Schools

For Stage 1 sampling (see estimation of sardine surface area, below), three categories of uncertainty sources are: 1) species misidentification, 2) school detection, and 3) school area determination. Species misidentification (particularly if other species should be mistaken for sardine during image analysis) is a concern, because it could lead to overestimation of sardine abundance. Activities to address this issue include: 1) adding to the library collection of verified school photographs for species identification, and 2) examining the spectral properties of sardine school images to discern if a sardine “signature” can be deciphered from the wavelength histograms.

Another challenge to the aerial survey approach is the negative impact of prohibitive weather conditions. Sampling the entire coast, and then conducting replicate transect sets, is difficult even under ideal conditions, given the limited amount of time available during the survey time window. The use of satellite imagery (see the Workshop paper on this topic) may afford a solution to this problem.

Additional details of the survey are provided in the document entitled “*West Coast Aerial Sardine Survey – 2010: Application for Exempted Fishing Permit*”. This document is available from the Council at: http://www.pcouncil.org/wp-content/uploads/F1a_ATT1_APP_EFP_APRIL_2010_BB.pdf.

Also provided for the Workshop is a discussion of lessons learned, including: 1) peer review advice for improvement (e.g. STAR panel and SSC recommendations), 2) activities presently underway to implement suggested survey improvements, and 3) suggestions for improvements to

future survey designs. Finally, consideration is given to: 1) promoting opportunities for collaboration and 2) potential linkages to other survey methods as a means of enhancing the assessment of Pacific sardine.

II. Aerial Sardine Survey Design

The West Coast Aerial Sardine Survey employs a two-stage sampling design. Stage 1 consists of aerial transect sampling to estimate the surface area (and ultimately the biomass) of individual sardine schools from quantitative aerial photogrammetry. Stage 2 involves at-sea sampling to quantify the relationship between individual school surface area and biomass. Sampling has previously been conducted in July (following closure of the directed fishery), through August, (and could potentially continue into early September). Sampling is conducted by NWSS in the northern region, and by CWPA in the southern region.

Stage 1: Aerial Transect Sampling

Logistics

The aerial survey employs the belt transect method using a systematic random sampling design; with each transect comprising a single sampling unit (Elzinga et al. 2001). Parallel transects are conducted in an east-west orientation, generally parallel to the onshore-offshore gradient of sardine schools distributed along the coast. Three alternative fixed starting points five miles apart were established, and from these points, three SETs of 66 transects were delineated for the survey. The order of conducting the three replicate SETs is chosen by randomly selecting one SET at a time without replacement. An example of the transect layout for one replicate is illustrated in Figure 1. Transects begin at the shore and extend westward for 38 statute miles in length; they are spaced 15 nautical miles (15 minutes) apart in latitude. Analysis for estimates of sardine biomass start 3 miles offshore to minimize potential presence of other coastal pelagic species nearshore [i.e. anchovy]. In addition to the 35 statute mile transects included in biomass estimates, the 0-3 statute mile segment directly eastward of each measured transect to the shore is also photographed and measured to evaluate the potential need for future modification of the survey design.

Experienced spotter pilots familiar with the sardine fishery and local conditions are contracted to participate in the survey, which includes flying transect replicates and directing point sets in their respective regions. Aerial resources include a Piper Super Cub and a Cessna 337 in the northern region, and a Partenavia 68 (operated by the California Department of Fish and Game), as well as a Cessna 172 and two Cessna 182s in the southern region.

To avoid the potential for “double counting” of sardine schools, aerial transect sampling is coordinated both within and between the two regions. For example, to conduct a SET, survey pilots in the northern region begin with transect number 1 at Cape Flattery in the north and proceed to transect number 26 off the southern Oregon coast. Pilots operating in the southern region begin with transect number 27 and proceed southward to transect number 66, south of the Channel Islands, in southern California. Within each region, pilots operate as a coordinated team, communicating via radio or cell phone. They take a “Leap-Frog” approach: for example -- plane 1 will fly transects 1-5 while plane 2 flies transects 6-10; then plane 1 will fly transects 11-15

while plane 2 flies transects 16-20, and so on. The actual number of transects flown in a day by each plane will be determined jointly by the survey pilots and field project leaders, and may be more or less than the example of five per plane given here.

Data Collection and Reduction

All survey airplanes are equipped with a Canon EOS 1D digital camera in an Aerial Imaging Solutions FMC mount system, installed either inside the fuselage of the plane, or mounted externally in a camera pod. This integrated system is used to acquire digital images and to log transect data. The system records altitude, GPS position, and spotter observations, which are directly linked to the time-stamped quantitative digital imagery. At the nominal survey altitude of 4,000 feet, the approximate width-swept by the camera with a 24 mm lens is 1,829 m (1.13 mi). Digital images are collected with 60% overlap to ensure seamless photogrammetric coverage along transects.

A Transect Flight Log Form is kept during the sampling of each transect for the purpose of documenting the observations of the pilot and/or onboard observers. Key notations include: 1) observations of school species identified and 2) documentation of any special conditions that could have an influence on interpreting the photographs taken along the transect.

To ground truth information and provide a cross comparison between survey aircraft, digital imagery of certain land-based features of known size (e.g., an airplane hangar, a football field, or a set of tennis courts) is collected at a series of altitudes ranging from 500 ft. to 4,000 ft. The observed vs. actual sizes of the objects is compared to validate camera performance and to evaluate photogrammetric error.

Digital images from the survey are analyzed to determine the number, size, and shape of sardine schools on each transect. Adobe *Photoshop Lightroom 2.0* software is used to make the sardine schools visible. Measurements of sardine school size (m²) and shape (circularity) are made using Adobe *Photoshop CS5-Extended*. Transect width is determined from the digital images using the basic photogrammetric relationship:

$$\frac{I}{F} = \frac{GCS}{A}$$

and solving for *GCS*:

$$GCS = \frac{I}{F} A$$

where *I* = Image width of the camera sensor (e.g. 36 mm), *F* = the focal length of the camera lens (e.g. 24mm), *A* = altitude, and *GCS* = “ground cover to the side” or width of the field of view of the digital image. Transect width is obtained by calculating the average of *GCS* for all images collected on transect. Transect length is obtained from the distance between start and stop endpoints using the GPS data logged by the data acquisition system.

Data Analysis

Estimation of total sardine biomass for the survey area is accomplished in a 3 step process, requiring: 1) measurement of individual school surface area on sampled transects, 2) estimation

of individual school biomass (from measured school surface area and estimated school density), and 3) transect sampling design theory for estimation of a population total.

Individual school surface area (a_i) is measured on the photo-documented transects using the measurement tool feature of *Adobe Photoshop*, that employs the photogrammetric relationships described above. Individual school density (d_i) is specific to school size and is determined from the empirical relationship between surface area and biomass obtained from Stage 2 (point-set) sampling (described below). Individual school biomass (b_i) is estimated as the product of school density and surface area ($b_i = d_i a_i$). The sum of individual school biomass (b_u) is then determined for each transect (u). The mean sampled biomass for the study area (\bar{b}) is computed as:

$$\bar{b} = \sum_{u=1}^n b_u / n .$$

Total biomass for the study area (\hat{B}) is estimated using the unbiased estimator for a population total (Stehman and Salzer 2000),

$$\hat{B} = N\bar{b} ,$$

with estimated variance (\hat{V})

$$\hat{V}(\hat{B}) = \frac{N^2 \left(1 - \frac{n}{N}\right) s_e^2}{n}$$

where N = the total number of transects possible in the region, n = the number of transects sampled in the region, and s_e^2 is the sample variance of \bar{b} (Cochran, 1977). The total number of transects possible in the region (N) is calculated by dividing the width of the entire region (W) by the average transect width (w).

The method of bootstrapping is also employed to determine the variance of the biomass estimate, by propagating error from Stage 1 and Stage 2 sampling, as described below under the heading “Evaluation of Sample Size Requirements for Stage 1 and Stage 2 Sampling”. The bootstrap estimate of variance, along with the point estimate of biomass, is provided to the NMFS/SWFCS for use in the Pacific sardine stock assessment.

Stage 2: At-Sea Point Set Sampling

Logistics

Empirical measurements of biomass are obtained by conducting research hauls or “point sets” on sardine schools at sea. Point sets are used to determine the relationship between individual school surface area (as documented with quantitative aerial photographs) and the biomass of individual fish schools. Logistically, it is desirable to have multiple boats available to be set by a single spotter plane in any given area. In this manner, after setting the first boat on a sardine school, the spotter pilot can direct a second (and potentially third, or fourth) boat to another school while the first boat is bringing fish on board. Typically, four purse seine vessels

participate in the survey in the northern region (NWSS), and eight vessels in the southern region (CWPA); four from Monterey and four from southern California.

For the purposes of the aerial survey, a valid point set is defined as a sardine school first identified by a survey pilot and subsequently captured in its entirety by a survey purse seine vessel. The criteria used for determining the acceptability of point sets for school density analysis is presented in Table 2.

Point sets are conducted over as wide an area as is feasible, using pre-specified quadrants in each region to guide the spatial distribution of sets (Figure 1).

Data Collection and Reduction

Point set sampling is based on school size, with the goals of: 1) obtaining a range of sizes representative of schools photographed on the transects, and 2) keeping within a size range consistent with the safe operation of the vessels participating in the survey. Thus, point sets are generally not attempted for schools larger than approximately 130 mt (approximately 10,000 m²). Point set sampling is distributed evenly between the northern and southern regions. For example, in the 2010 West Coast Aerial Sardine Survey EFP proposal, 2,100 mt was requested for each region in order to conduct 56 point sets in the north, and 56 in the south (Table 3).

An evaluation of sample size requirements, derived from a simulation analysis using 2009 survey data, is discussed below. While it is clear that a larger sample size would be beneficial, the proposed sample size of $n = 56$ point sets per region was considered to be a realistic request for the 2010 EFP with the resources available.

For fully captured schools, each of the following are determined from biological sampling of the point set hauls: 1) total weight of the school, 2) numbers per unit weight, and 3) species composition. Additionally, school height in the water column is recorded using vessel sonar and down-sounder equipment.

Data Analysis

The relationship between school surface area and biomass is determined by fitting the three parameter Michaelis-Menten model assuming log-normal error, i.e., $\ln(\text{Density}) = (a + b \cdot \text{Area}) / (c + \text{Area})$, to the observations of school surface area and biomass obtained from the valid point sets. An example of this relationship (derived from 2008 and 2009 data) is presented in Figure 2.

Biological Sampling of Point Sets

Fishermen participating in the survey are instructed to keep the point set hauls in separate holds upon capture so that tonnage of each aerially photographed and measured haul can be determined separately upon landing. Fish are collected at fish processing plants upon landing. Samples are collected from the unsorted catch while being pumped from the vessels. Fish are taken systematically at the start, middle, and end of each set as it is pumped. These three samples are then combined, and a random subsample of fish ($n = 50$) is taken from the pooled sample. Length, weight, sex, and maturity data are collected for each sampled fish. Sardine weights are taken using an electronic scale accurate to 0.5 gm; lengths are taken using a millimeter length

strip provided attached to a measuring board. Standard length is determined by measuring from tip of the snout to the last vertebrae. Sardine maturity is recorded based on maturity codes (female- 4 point scale, male- 3 point scale) supplied by Beverly Macewicz NMFS, SWFSC. A subsample of 25 fish from each point set sample is frozen and retained for future collection of otoliths.

Evaluation of Sample Size Requirements for Stage 1 and Stage 2 Sampling

In order to develop sample size recommendations for the West Coast Aerial Sardine Survey, an analysis of the data collected in 2009 was conducted to determine the effect of varying the number of transects (from Stage 1 sampling) and point sets (from Stage 2 sampling) on the variability of the final estimate of sardine population biomass from the survey.

A stochastic simulation algorithm was coded using *R* statistical analysis software (*version 2.10.1*), to estimate the variance of the survey biomass estimator. Sampling error from Stage 1 and Stage 2 sampling was propagated through to determination of the final biomass estimate. A similar analysis was used to generate simulated data sets of varying size, to evaluate how the variance of the final biomass estimate changes as the number of point sets increases. The simulated data sets ranged in size from $n = 23$ to $n = 189$. An additional set of simulations was run with the number of transects doubled from the actual number (41) to 82. For $n = 41$ transects, the biomass CV ranged from 0.74 to 0.54, and leveled out around $n = 125$ point sets. A similar trend was observed for $n = 82$ transects; CV declined from 0.55 to 0.39 at the sample sizes of 23 vs. 189 point sets, respectively. The results of the sample size simulations are presented in Figure 3.

These results show the value of obtaining additional point sets to reduce the uncertainty of the survey biomass estimate. They also illustrate that increasing the level of transect sampling can also be expected to reduce the overall variance of the biomass estimate. The results also demonstrate that the sample size of $n = 56$ point sets per region proposed for 2010 sampling (totaling 112 point sets) is practical given the time constraints and resources available.

III. Lessons Learned

In the course of conducting both the NWSS pilot study work in 2008, and subsequently the larger scale EFP aerial sardine survey by NWSS/CWPA in 2009, useful lessons have been learned for potential improvements in the survey design and for future implementation.

Sources of uncertainty identified for the West Coast Aerial Sardine Survey by the May, 2009 STAR panel are presented in Table 1. Review of the categories of uncertainty listed, particularly with reference to relative potential magnitude and direction (i.e. over or under estimation of biomass), is an informative way to consider some of the advantages vs. challenges/limitations of the aerial sardine survey approach.

Peer Review Recommendations

Listed below is a compilation of peer review recommendations, along with a brief description of progress made to date, and future plans currently in place to implement them.

A. Recommendations of the STAR Panel held at the NOAA / Southwest Fisheries Science Center, La Jolla, California, September 21-25, 2009.

Research Recommendations

The Panel noted that most of the short-term recommendations of the May 2009 Panel had been implemented and identified a number of additional recommendations (not in priority order).

1. Further attempt to quantify (and then account for) the impact of “edge effects” on photographs, including the effect of calculating school weight for an estimate of school area, in which only part of a school is visible in a photograph.
An analysis is currently underway to examine the magnitude of “edge effects”. The procedure includes selecting from the 2009 survey archive, a set of photographs with multiple sardine schools present. Using Adobe Photoshop CS5, a line is drawn through the center of the selected photographs, and the two split areas of the schools bisected by this process are documented for analysis. To increase the sample size, this analysis will also be conducted with photographs from the 2010 summer and fall surveys, when available. Target date for completion: October/November 2010.
2. Further attempt to calibrate the scheme used to estimate surface area from photographs. Specifically, calibration experiments should consider objects which do not have a regular shape (e.g., a baseball field was identified as a possible “target”) and explore whether there are “analyst effects” and/or “photograph effects” by analyzing existing and future calibration data.
An analysis is currently underway to further calibrate measurements from photographs to evaluate “analyst” and “photograph” effects. The procedure includes selecting from the 2009 survey archives, a set of photographs with irregularly-shaped target objects of already known (or measurable) size present in the image. To increase the sample size, this analysis will also be conducted with photographs from the 2010 summer and fall surveys, when available. Target date for completion: October/November 2010.
3. Future research should consider methods that can be used to determine the proportion of sardine schools that are visible from aircraft. Acoustics (e.g., from fishing vessels) was identified as one potential method to achieve this goal.
As part of the Fall Pilot Study, a comparison of school sightings from aerial photographs will be made with acoustic sampling of the same transects during the collaboration with the CalCOFI cruise in the S. Ca. Bight. Target date for completion: October/November 2010.
4. Continue to refine the approach used to identify sardine schools in photographs. The use of mosaicing and recording lines on the images were identified as possible areas of investigation.

The procedure of mosaicing requires detailed, quantitative GPS data for each image taken along a transect, in order to geo-reference the photographs with respect to one another. As part of the Summer Survey and Fall Pilot Study in 2010, a new roll/pitch (IMU) sensor will be incorporated into the quantitative FMC camera systems deployed in California. This roll/pitch data will be used to investigate the feasibility of geo-referencing the survey photographs. Target date for completion: early-mid 2011.

5. Examine the trade-offs associated with different flight heights between area surveyed and the ability to fly transects.

An analysis of sample size requirements (see Figure 3) showed that there is value associated with obtaining more survey area coverage (e.g. by increasing survey altitude). Additional (and faster) airplanes are planned for the 2010 survey to improve the likelihood of increasing area coverage and also completing replicate transects.

6. Estimate the variation in the perceived size of sardine schools using multiple photographs of the same schools.

As part of the Stage 2 sampling, schools are photographed before and during the process of conducting the point sets. Multiple photographs of the same school (3 or more) are taken prior to the vessel capture of the school, and these photographs can provide data to conduct this analysis. The procedure will be to select from the 2009 survey archives, a set of photographs inclusive of multiple photographs of the same school present. Variability in school size between photographs will be examined. To increase the sample size, this analysis will also be conducted with photographs from the 2010 summer and fall surveys, when available. Target date for completion: early-mid 2011.

7. Refine the method of variance estimation to account for all sources of uncertainty. Specifically, identify methods (e.g., based on bootstrapping; see Adjunct 2) that can take into account: (a) inter-transect variation in density, (b) uncertainty about the school weight – school area relationship, (c) variation for individual schools about the school weight – school area relationship, and (d) uncertainty arising from attempting to estimate the size of schools.

An analysis of sample size requirements demonstrated the usefulness of a method of variance estimation, based on bootstrapping, to account for (a) and (b), above. An extension of this approach, using the data collected in the analyses described in Research Items 2 and 6 (above), can be used to evaluate the additional sources of uncertainty identified in (c) and (d), above. Target date for completion: early-mid 2011.

8. Consider the use of geostatistical methods to estimate sardine abundance and the uncertainty of the estimate, especially if the likelihood of obtaining multiple replicates within a single aerial survey is likely to remain low.

The classical random sampling approach is preferred if logistics permit, however, geostatistical methods may be employed in the future if the 2010 survey again fails to yield multiple replicates.

9. Consider further stratification of the area surveyed during the aerial survey. In particular, consider the benefits of offshore strata. Such strata could have lower coverage, consistent with likely lower density.

It is anticipated that increased (coastwide) survey coverage and transect replication (such as that planned for 2010) will help to better evaluate the potential advantages of refinements in stratification.

10. Consider whether it is possible to use acoustics to calculate the density associated with schools that are too large to be sampled using point sets. Consideration must be given to the impact of vessel avoidance in the analysis of such data.

As part of the 2010 Fall Pilot Study, which incorporates an acoustic component, it should be possible (data permitting) to evaluate the feasibility of using acoustics to calculate the density of schools that are too large to be sampled using point sets. Target date for completion: early-mid 2011.

11. Collect data on environmental conditions from point sets (e.g., using onboard loggers) and explore whether environmental covariates explain some of the variation about the school weight – school area relationship.

As part of the 2010 Fall Pilot Study, point set data will be collected in areas where CalCOFI surveys will be logging environmental variables. It may be possible to begin to explore whether environmental covariates can help to explain some of the variation about the school weight – school area relationship with this pilot study data. Target date for completion: early-mid 2011.

12. Refine how photographs are analyzed to account for pitch and roll.

Aerial transects planned for California in 2010 will be conducted using the same camera equipment employed in the 2009 survey – with the addition of a new roll/pitch (IMU) sensor (see Research Item 4, above). Results from these transects will afford the opportunity to evaluate how the IMU data may be used to improve how photographs are analyzed to account for pitch and roll in future surveys. Target date for completion: early-mid 2011.

13. Provide all of the data on which the aerial survey estimate is based (including the original photographs and details regarding school size identification and quantification) to the STAT.

An archival procedure with standard file naming conventions has been developed. All of the 2009 Survey data on which the aerial survey estimate of sardine abundance is based has been compiled and indexed. The data are archived on a 1TB external hard drive. A copy of the 1TB archive has been provided to Dr. Kevin Hill at the SWFSC. This procedure will be followed again after the 2010 Survey.

Additional recommendations from the May 2009 STAR Panel:

- Record qualitative information related to processing photographs and the difficulty in assigning species and calculating school areas.

The recording of qualitative information with respect to photograph processing is routine procedure for the Photo Analysis Team. An effort will be made to further formalize how this information is collected and reported in the future.

- Observer effects when viewing photographs could be evaluated using double-blind comparisons and similar techniques.

The analyses described in Research Item 2 address this recommendation. Target date for completion: early-mid 2011.

B. Recommendations of the Scientific and Statistical Committee - April, 2010.

Exerpts from the Draft Minutes of the April, 2010 meeting of the SSC

1. The SSC suggests that ... aerial transects occur before the point sets, and that the point sets reflect the size distribution of schools identified in the transects... adequate spatial stratification would divide the survey into four equally sized areas with no less than 15 percent of point sets allocated to each quadrant, subject to the presence of sardine schools in each quadrant.

The study design has been modified to address the suggestion for point set spatial stratification. Point set sampling quadrants were established for both the northern and southern regions (Figure 1). Due to logistical and weather constraints, it is possible that aerial transects may not occur prior to the point sets.

2. [Regarding the California Fall Pilot Study] ...The SSC recommends that both point sets and LIDAR detections be stratified across sardine schools of a large range of sizes, so that variation in the surface area/biomass relationship can be adequately evaluated.

Size stratification of point set sampling is specified in the 2010 EFP application document (Appendix I, Adjunct 1, Table 1), page AI-52.

IV. Workshop Discussion Points

The participants of the West Coast Sardine Survey welcome the notion of exploring opportunities for collaboration with government. It is hoped that venues such as this Workshop will lead to productive, cooperative research ventures.

Clear linkages exist between the aerial sardine survey (as presently designed) and the other remote detection technologies, such as LIDAR and satellite imagery, also discussed at this Workshop. The California Fall Pilot Study will afford an excellent opportunity to evaluate potential ways that LIDAR and acoustic technology may be combined with aerial photography. Also, further exploration of the potential for using satellite imagery (as a supplement, or in place of aerial photography) is desirable.

V. Bibliography

Cochran, W.G. 1977. Sampling Techniques (3rd edition). John Wiley, New York, NY, USA.

Elzinga, C. L., D. W. Salzer, J. W. Willoughby, and J. P. Gibbs. 2001. *Monitoring Plant and Animal Populations*. Blackwell Science, Inc., Maiden, MA.

Hill, K. T., E. Dorval, N. C. H. Lo, B. J. Macewicz, C. Show, and R. Felix-Uraga. 2009. Assessment of the Pacific sardine resource in 2009 for U.S. management in 2010. Pacific Fishery Management Council, Portland, OR.

Jagiello, T.J., Hanan, D., and R. Howe. 2009. West Coast Aerial Sardine Survey. Sampling Results in 2009. Prepared for California Wetfish Producers Association, and the Northwest Sardine Survey. Submitted to Pacific Fishery Management Council, Portland, OR, October 14, 2009.

Stehman, S. and D. Salzer. 2000. Estimating Density from Surveys Employing Unequal-Area Belt Transects. *Wetlands*. Vol. 20, No. 3, pp. 512-519. The Society of Wetland Scientists, McLean, VA.

Wespestad, V., Jagiello, T. and R. Howe. 2008. The Feasibility Of Using An Aerial Survey To Determine Sardine Abundance Off The Washington-Oregon Coast In Conjunction With Fishing Vessel Observation Of Surveyed Schools And Shoals. Report Prepared For: Northwest Sardine Survey, LLC. 12 Bellwether Way, Suite 209, Bellingham, WA 98225.

Figure 1. Maps showing an example of the transect layout for one sampling replicate (SET). Four quadrants are specified for the spatial distribution of point sets in each region.
Top: Northern region; Bottom: Southern region -- California.

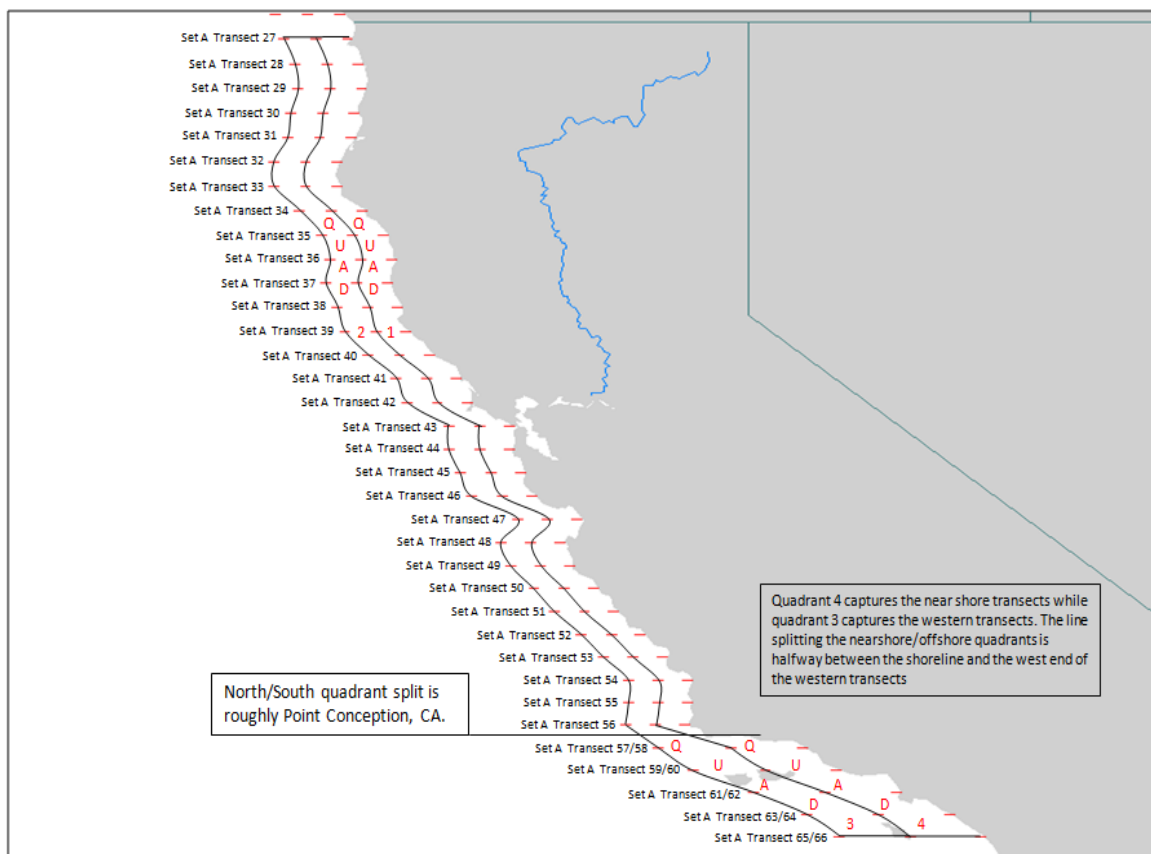
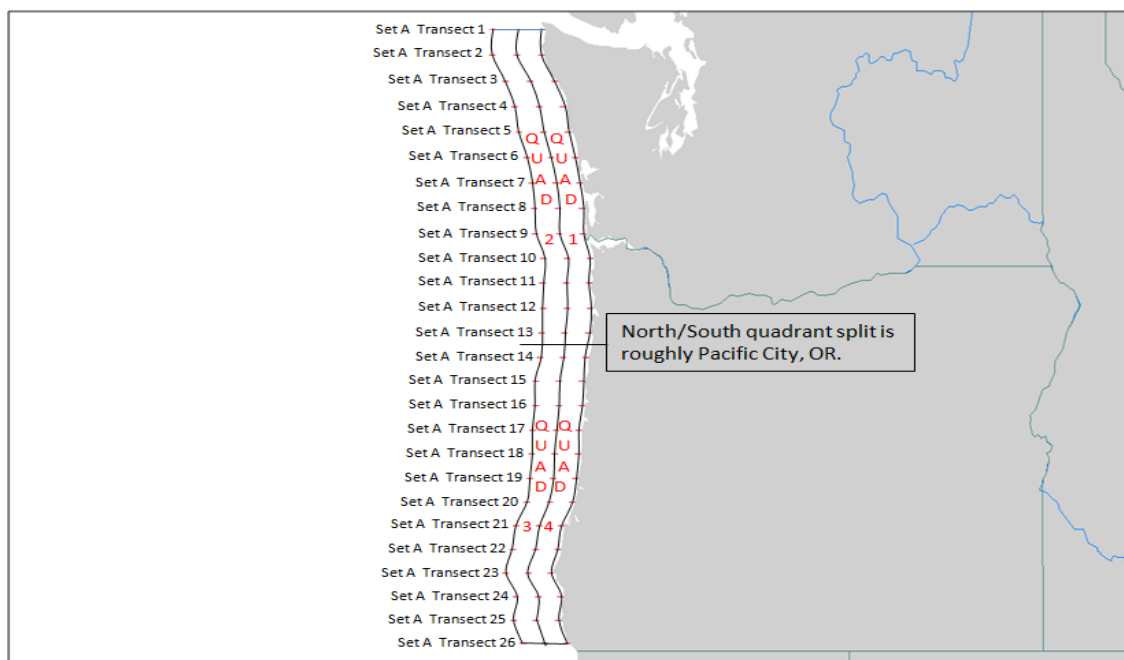


Figure 2. Relationship of surface area (m^2) (x axis) vs. density (y axis) determined from point sets sampled in 2008 and 2009.

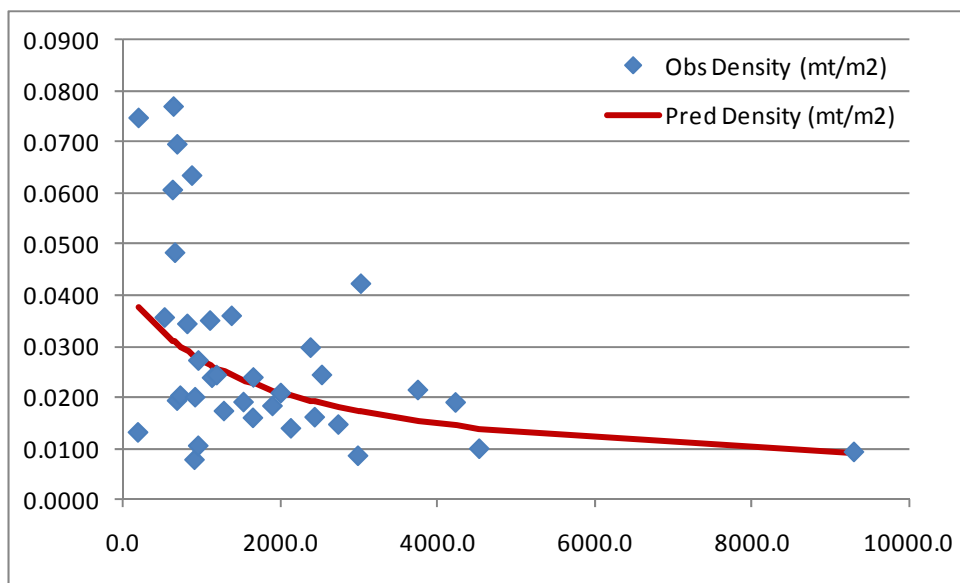


Figure 3. Bootstrap simulation results showing CV as a function of point set sample size for $n = 41$ (solid line), and $n = 82$ aerial survey transects (dashed line).

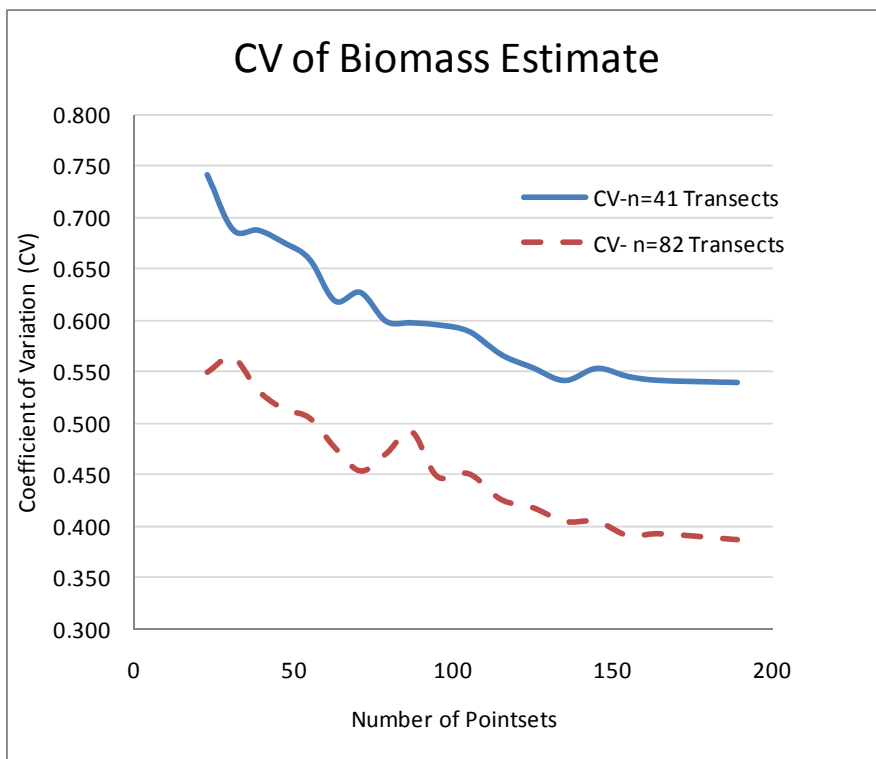


Table 1. Sources of uncertainty in the aerial sardine survey identified by the May, 2009 STAR Panel

Stage 1 – Estimation of sardine school area

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Category: Species misidentification		
Type 1: Sardine misidentified as other spp./features	Underestimate	Directed sets, jigging, include low overflight
Type 2a: Other spp. misidentified as sardines	Overestimate	Directed sets, jigging
Type 2b: Other features misidentified as sardine	Overestimate	Avoid cloudy conditions ??
Density dependent misidentification (a nonlinearity)	Hyperstability?	Long-term comparisons
Variability among pilots		
Category: School detection (note: timing needed for assessment schedule is not optimal for survey conditions)		
Schools too deep	Underestimate	Quantify water clarity (e.g. secchi depth), Echo sounder evidence
Schools lost in glare	Underestimate	Time of day, compare adjacent frames
Schools too diffuse (hypothetical)	Unknown	Relate to behavioural patterns?
Marginal cloud cover, reduced visibility	Underestimate	Determine range of acceptable conditions
Sea state	Underestimate	Determine range of acceptable conditions
Technician variability–image enhancement	Unknown	Double-blind re-analyses
Weather is consistently prohibitive	Unknown	Use better season and delay input one year
Category: School area determination		
Calibration of scale (photogrammetry)	Overestimate (maybe neutral)	Continue calibration
Calibrate distortion at edge of frame	Unknown	Continue calibration
Precision and repeatability	Unknown	Repeat photos of same school over time; Compare morning and afternoon views
Schools extending outside visual frame	Depends on B/A relationship	Problem mainly if nonlinearity exists
Diffuse school boundary	Overestimate?	Disturb with vessel and compare area?
Complex shape or diffuse	Overestimate?	Repeat photos of same school over time; Disturb with vessel and compare
Technician variability–image enhancement	Unknown	Blind” reanalyses of photos, within and among technicians.

Table 1, continued.

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Comparability to images in Stage 1	Unknown	Choose conditions and school types similar to aerial survey. Use similar altitude.
Pro-sardine target selection	Overestimate	Select schools only on size criterion
Nonlinear biomass/area relationship	Unknown	Increase sample size, contrast
Statistical imprecision	Unknown	Increase sample size
Regional differences	Unknown	Compare northern and southern cases
Behavioural patterns		
Feeding, spawning, transiting	Unknown	Stratification
Mixed species	Unknown	
Response to fishing vessel	Overestimate	Get photo before vessel approaches
Oceanographic conditions (e.g., El Nino)	Overestimate (contraction)	Caution in among-year data sharing
Distance offshore	Unknown	
Present but undetectable-directed sets impossible	Underestimate	Conduct blind sets (e.g., Percy's work)
Variable relationship depending on school thickness	Unknown	Voluntary logbooks at time of survey to compare school thicknesses among years
Density-dependent mixed schooling	Unknown	Long-term fishery catch compositions

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Abundance estimation		
Pre-integrate area—works if there is linearity	Unknown	Depends on Stage 2 results; Edge effect is neutral if linear
Integrate biomass over schools—works best if nonlinear	N/A	Need to deal with edge effects
Other		
Survey stratification (transect density depends on school density)	N/A	Possible with further experience, but not currently proposed
Survey does not cover whole area	Underestimate	Maybe extend transects offshore; Go into Canada, Mexico

Table 2. Aerial Survey Point Set Protocol

- 1) Sardine schools to be captured for point sets will first be selected by the spotter pilot and photographed at the nominal survey altitude of 4,000 ft. After selection, the pilot may descend to a lower altitude to continue photographing the school and setting the fishing vessel.
- 2) It is essential that any school selected for a point set is a discrete school and is of a size that can be captured in its entirety by the purse seine vessel; point set schools may not be a portion of a larger aggregation of fish.
- 3) To ensure standardization of methodology, the first set of point sets taken by each participating pilot will be reviewed to ascertain that they meet specified requirements. From that point forward, point set photos will be reviewed routinely to ensure that requirements are met.
- 4) A continuous series of photographs will be taken before and during the vessels approach to the school to document changes in school surface area before and during the process of point set capture. The photographs will be collected automatically by the camera set at 60% overlap.
- 5) Each school selected by the spotter pilot and photographed for a potential point set will be logged on the spotter pilots' Point Set Flight Log Form. The species identification of the selected school will be verified by the Captain of the purse seine vessel conducting the point set, and will be logged on the Fishermans' Log Form. These records will be used to determine the rate of school mis-identification by spotter pilots in the field and by analysts viewing photographs taken at the nominal survey altitude of 4,000 ft.
- 6) The purse seine vessel will wrap and fully capture the school selected by the spotter pilot for the point set. Any schools not "fully" captured will not be considered a valid point set for analysis.
- 7) If a school is judged to be "nearly completely" captured (i.e. over 90% captured), it will be noted as such and will be included for analysis. Both the spotter pilot and the purse seine vessel captain will independently make note of the "percent captured" on their survey log forms for this purpose.
- 8) Upon capture, sardine point sets will be held in separate holds for separate weighing and biological sampling at the dock.
- 9) Biological samples of individual point sets will be collected at fish processing plants upon landing. Samples will be collected from the unsorted catch while being pumped from the vessels. Fish will be systematically taken at the start, middle, and end of a delivery as it is pumped. The three samples will then be combined and a random subsample of fish will be taken. The sample size will be $n = 50$ fish for each point set haul.
- 10) Length, weight, maturity, and age structures will be sampled for each point set haul and will be documented on the Biological Sampling Form. Sardine weights will be taken using an electronic scale accurate to 0.5 gm. Sardine lengths will be taken using a millimeter length strip provided attached to a measuring board. Standard length will be determined by measuring from sardine snout to the last vertebrae. Sardine maturity will be established by referencing maturity codes (female- 4 point scale, male- 3 point scale). Otolith samples will be collected from

Table 2, continued.

- n = 25 fish selected at random from each n = 50 fish point set sample for future age reading analysis. Alternatively, the 25 fish subsample may be frozen (with individual fish identified as to sample number, point set, vessel and location captured, to link back to biological data) and sampled for otoliths at a later date.
- 11) School height will be measured for each point set. This may be obtained by using either the purse seine or other participating research vessels' hydroacoustic gear. The school height measurements to be recorded on the Fishermans' Log Form are: 1) depth in the water column of the top of the school, and 2) depth in the water column of the bottom of the school. Simrad ES-60 sounders will be installed on three purse seine vessels. Data collected by the ES-60 sounders will be backed-up daily and archived onshore.
 - 12) Point sets will be conducted for a range of school sizes. Point sets will be targeted working in general from the smallest size category to the largest. The field director will oversee the gathering of point set landing data and will update the list of point sets needed (by size) daily for use by the spotter pilot. Each day, the spotter pilot will operate with an updated list of remaining school sizes needed for analysis. The spotter pilot will use his experience to judge the surface area of sardine schools from the air, and will direct the purse seine vessel to capture schools of the appropriate size. Following landing of the point sets at the dock, the actual school weights will be determined and the list of remaining school sizes needed will be updated accordingly for the next day of fishing. If schools are not available in the designated size range, point sets will be conducted on schools as close to the designated range as possible. Pumping large sets onto more than one vessel should be avoided, and should only be done in the accidental event that school size was grossly underestimated.
 - 13) The field director will also oversee the spatial distribution of point set sampling, to ensure adequate dispersal of point set data collection.
 - 14) Photographs and FMCdatalogs of point sets will be forwarded from the field for lab analysis daily. In the northern region, these will be collected by Mr. Howe directly. In the southern region, they will be overnighed by Dr. Hanan to Mr. Howe via FedEx or UPS.
 - 15) The total landed weight of point sets taken will not exceed the EFP allotment per area.
 - 16) The following criteria will be used to exclude point sets from the density analysis (reasons used to deem a point set "unacceptable"). Mr. Howe will make the final determination of point set acceptability in the lab. A preliminary judgment will be made in the field, generally at the end of each day (or sooner) by the Field Project Leader in each region, to ensure ongoing sampling is being properly done.

1	Percent captured	School is judged to be less than 90% captured
2	No photograph -1	No photograph of vessel was documented (camera off)
3	No photograph -2	No photograph of vessel was documented (camera on)
4	No photograph -3	Photograph available, but late (vessel is already pursuing the catch)
5	School not discrete	Sardine captured was only a portion of a larger school ("cookie cutter")
6	Mixed hauls	Multiple point sets were mixed in one hold

DRAFT 5-22-2010 DRAFT 5-22-2010 DRAFT 5-22-2010

Table 3. Distribution of point set sizes proposed for each region (northern and southern) for the 2010 Coastwide Summer Aerial Sardine Survey. Total Weight is in metric tons.

Size (m ²)	Weight (mt)	Total Weight	Number of Point Sets
100	3.8	31	8
500	10.6	85	8
1000	17.0	136	8
2000	26.5	212	8
4000	51.9	415	8
8000	70.5	564	8
10000	82.1	657	8
		2099	56